Student Design Competition: Materials and Structures for Extreme Environments

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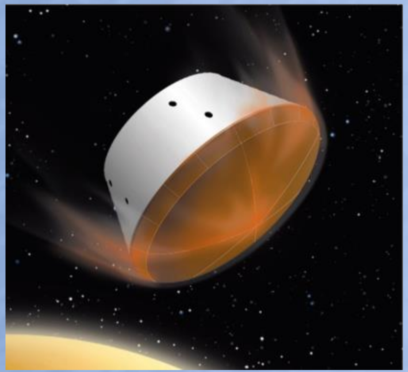
What is an Extreme Environment?

- Application Areas in Aeronautics
  - Aircraft engine components and sensors
  - Aircraft structures
  - New aircraft power and propulsion system components

- Application Areas in Space
  - Propulsion systems
  - Primary structures
  - Insulation systems
  - Tank structures
  - Active components and structures
  - Thermal protection systems



Some Conditions in Extreme Environments

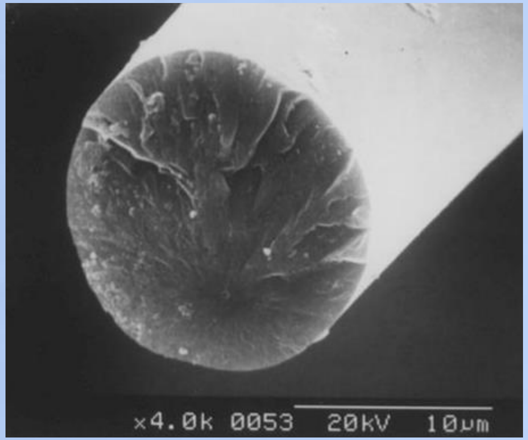
- High, low, and cyclical temperatures
- High stress
- High strain
- Impact loading
- Oxidizing
- Vacuum
- High current
- High voltage
- Radiation
- Any and all combinations of these and many more

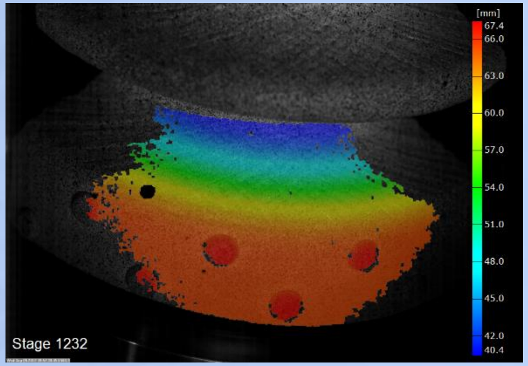
Top Down Approach (Tech Pull)

- Assess the requirements of the application
- Assess potential design solutions and material requirements
- Assess potential materials solutions
- Identify gaps in performance or understanding of the response of the structure or material
- Develop new methods for design, analysis, and characterization as needed
- Develop new materials to meet requirements of the application as needed
- Certify new material or method
- Apply new technology

Bottom Up Approach (Tech Push)

- Investigate fundamental characteristics of materials and structures
- Develop new technologies from advanced understanding of the underlying physics
- Identify opportunities to apply new technologies to do something new or do something old in a better way
- Determine gaps or shortfalls of the new technology
- Refine the new technology
- Apply the new technology





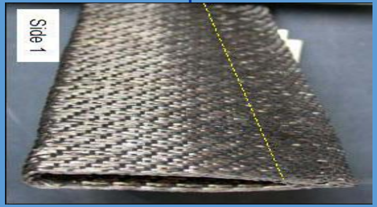
Materials and Structures (LM) Division Branches

- LMA- High Temperature and Smart Alloys
- LMC- Ceramic and Polymer Composites
- LMD- Structural Dynamics
- LME- Environmental Effects and Coatings
- LMM- Structural Mechanics
- LMN- Materials Chemistry and Physics
- LMP- Mechanical Systems Design and Integration
- LMR- Rotating and Drive Systems
- LMS- Multiscale and Multiphysics Modeling
- LMT- Mechanisms and Tribology

Materials and Structures Division (LM)

High Temperature Materials

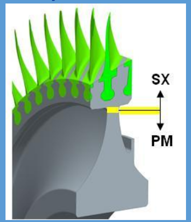
Ceramic Matrix Composite



Protective Coatings

Thermal Protection Seal

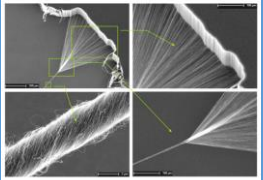
Hybrid Disk



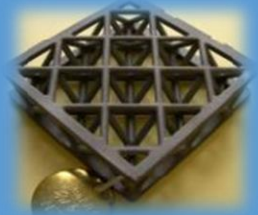
Lightweight Concepts

Hybrid Composite Gear

Nanotube Yarn



Lattice Block



Flexible Aerogel

Power System Materials

Materials for High Power Density Electric Motors

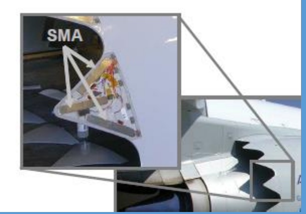
Lightweight Power Transmission Cable

Solid Oxide Fuel Cell Material

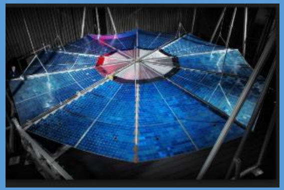
Mechanisms and Drive Systems

High Efficiency Gear

Shape Memory Alloy-Based Actuation

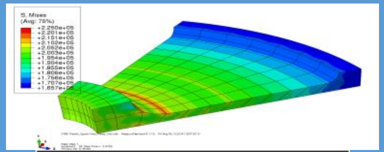


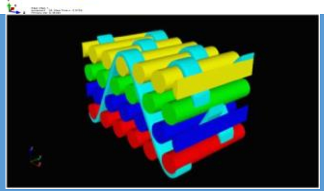
Deployable Structure

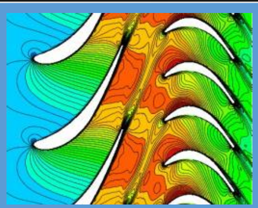


Spring Tire

Computational Modeling

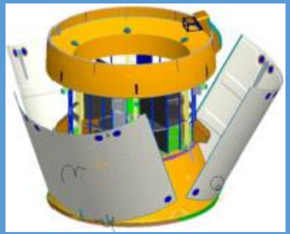






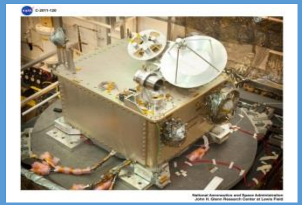
Flight Structures

Orion Fairing Jettison



EFT-1

Vibration Testing



Large Composite Structures

Importance of Materials in Aircraft Systems

- Structural
  - Wing skins, fuselage, tanks, landing gear…
- Electrical
  - Avionics, actuators, entertainment systems…
- Hydraulic
  - Actuators, pumps, lines, valves…
- Thermal
  - Cabin heating/cooling, parasitic heat…
- Acoustic
  - Noise damping panels, engine liners…
- Aesthetic
  - Seats, wall panels, floor coverings, windows…

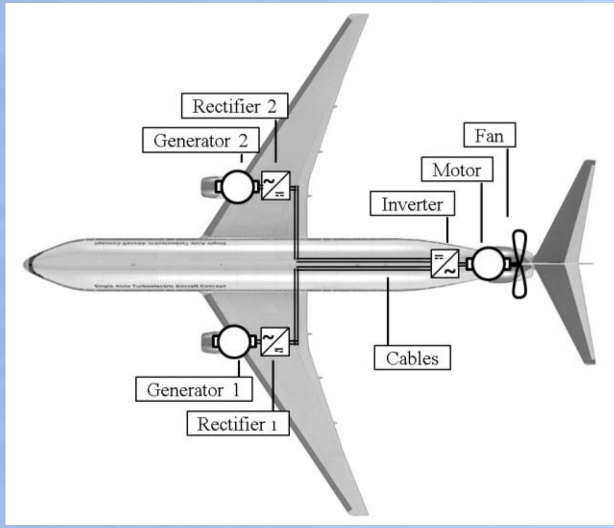
Some Current Materials Challenges for Aircraft

- More electric aircraft (including electric propulsion)
  - Materials for lighter motors/generators, cables, batteries, power electronics…
- More efficient, higher temperature engines
  - Materials for high temperature sensors, turbine blades, oxidation coatings, combustor liners, high turbine stresses…
- Composite primary structure
  - Impact tolerance, flaw detection, lightning strike, thermal and mechanical cycling, moisture tolerance, analysis and prediction, certification…

Why Electric Propulsion?

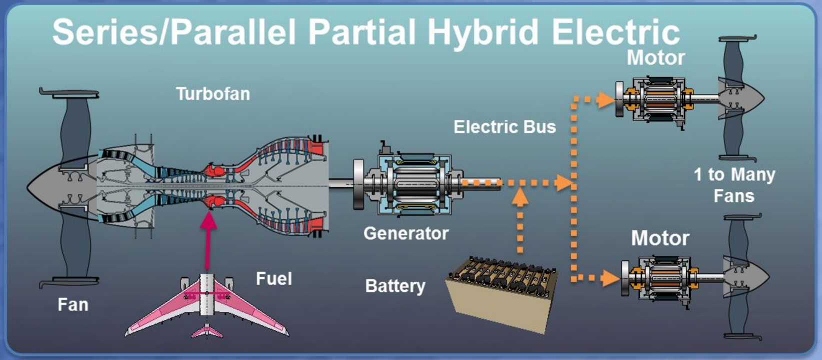
There are 2 main reasons to pursue electric aircraft propulsion:

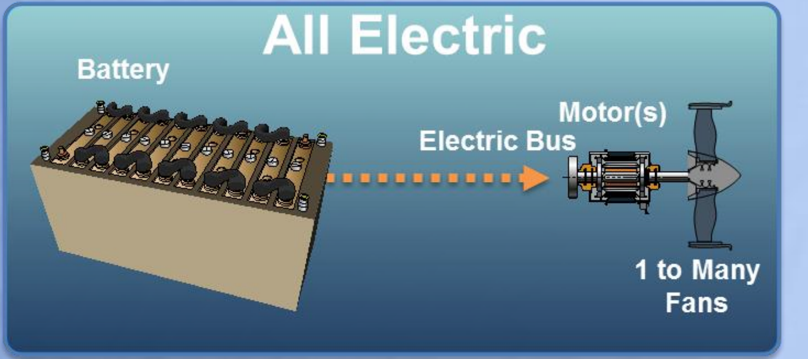
- Do something better by doing it in a different way
  - Operate the aircraft or aircraft systems in new ways, new missions, new configurations
  - Integrate the propulsion system with the airframe in a different way
- Change the source of energy
  - Carbon reduction by using renewables



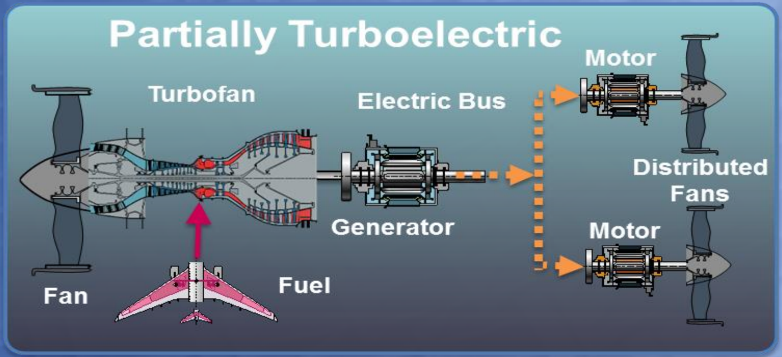
Electrified Aircraft Propulsion Terminology

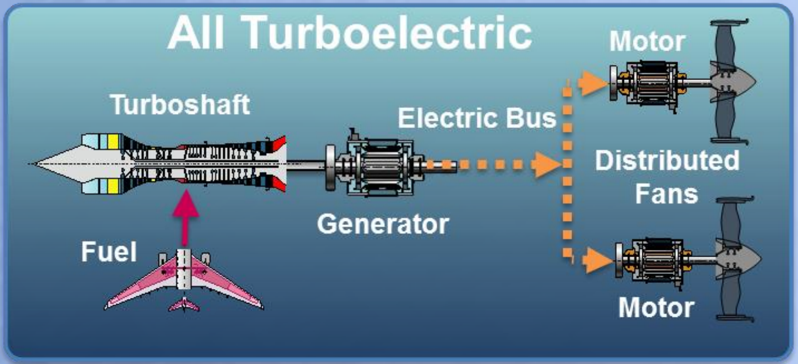
- **Hybrid electric powertrain systems use engine derived power combined with electrical energy storage.**
  - Many configurations exist with difference ratios of turbine to electrical power and integration approaches



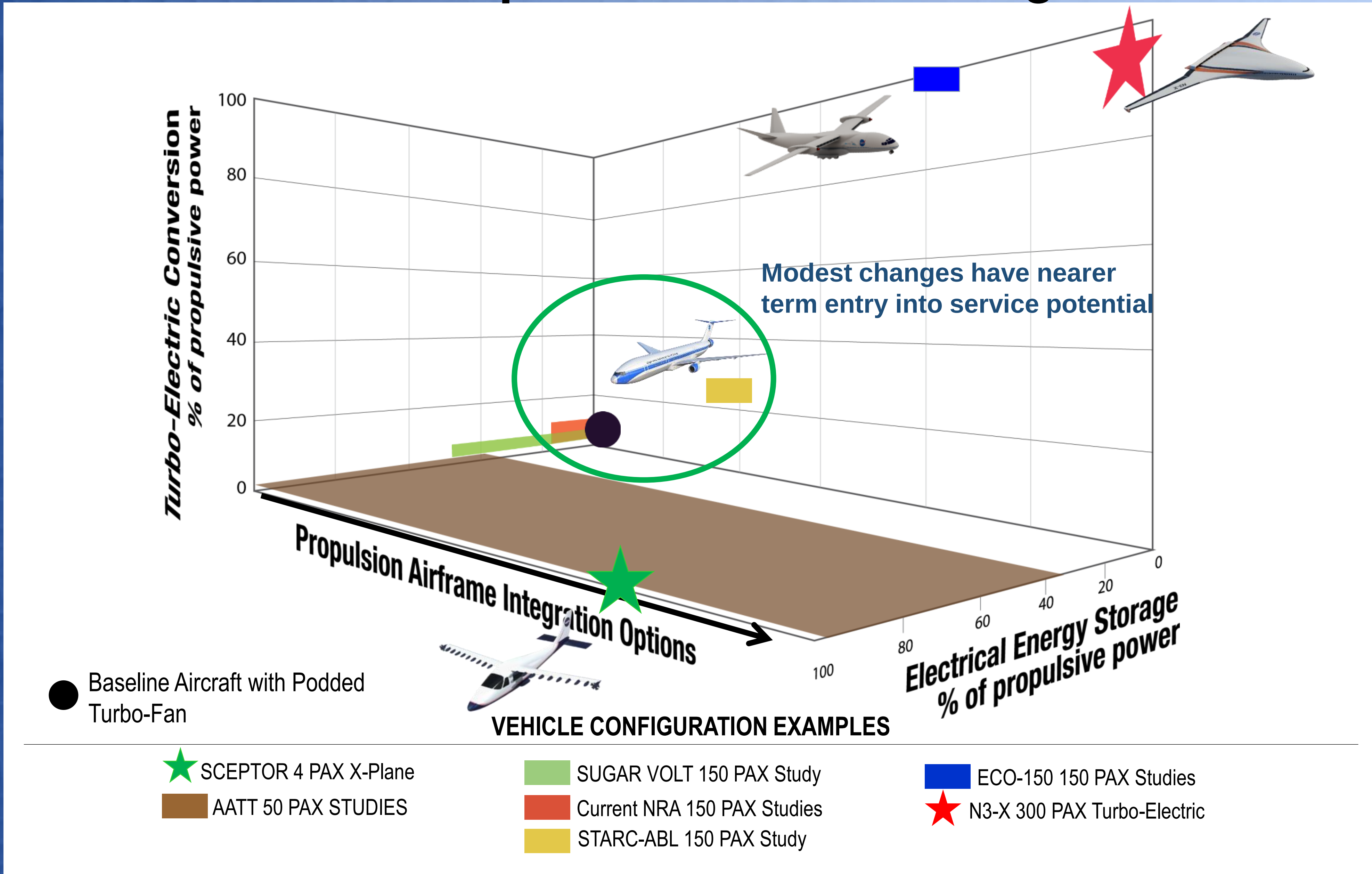


- **Turboelectric systems use onboard generation as power source.**
  - Partially turboelectric systems split the thrust between a turbo fan and the motor driven fans





Electrified Propulsion Vehicle Configurations

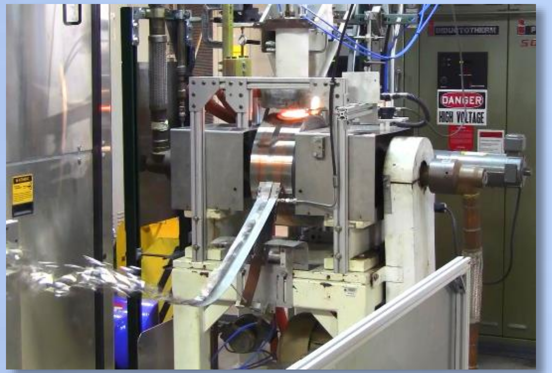


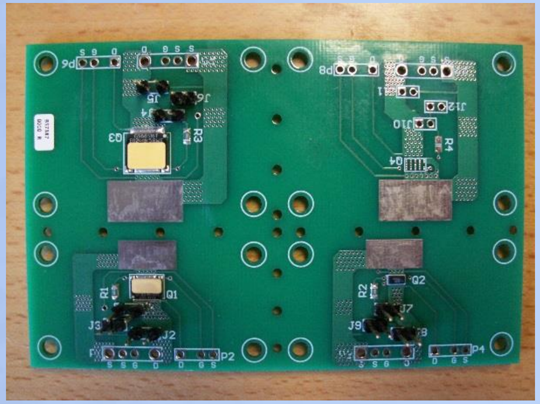
Some Challenges in Electric Aircraft Propulsion

- A turbine engine driving a fan is extremely efficient. Replacing a shaft with electric machines and electronics adds weight, losses, and complexity. There must be benefits at the aircraft level to warrant the use of electric propulsion.
- The flexibility that electric propulsion creates opens up the design space dramatically (too many options).
- The electrical components that are available today mostly haven't needed to meet weight and durability requirements demanded by an aircraft propulsion.

Research Areas for Electric Propulsion

- Electric Machines (motors and generators)
  - Design, magnets, magnetic steels, conductors, thermal management, superconductors…
- Power Electronics
  - Design, wide band gap semiconductors, inductors, capacitors, control approaches, cryogenic cooling…
- Cables and Power Distribution
  - Insulation, superconductors, fault detection…
- Energy Storage and Conversion
  - Batteries, SMES, flywheels, structural batteries, fuel cells…
- Thermal Management
  - Cryogenic fuel cooling, heat exchangers, cryocoolers, thermally conductive insulators…





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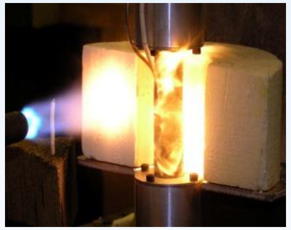
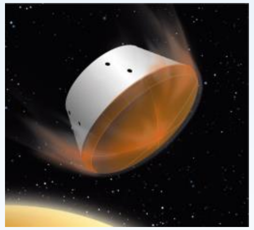
Back up slides follow

Materials Research Driven by Key Aerospace Challenges

Higher temperature and harsh environment for aerospace propulsion and planetary entry





Lightweight requirements for large structures

Low carbon and low emission aircraft

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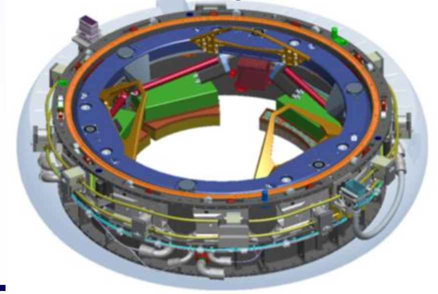
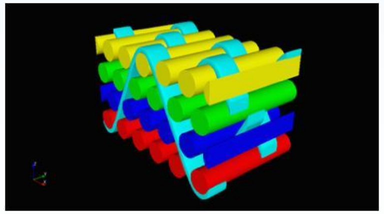
Lightweight and durable mechanical system/mechanisms



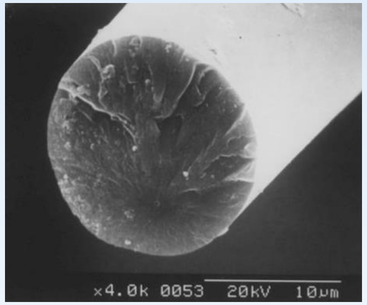
Long-term durability in harsh environments

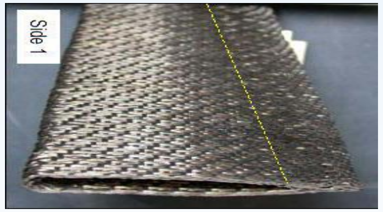


Computational modeling across multiple length scales

High Temperature Materials

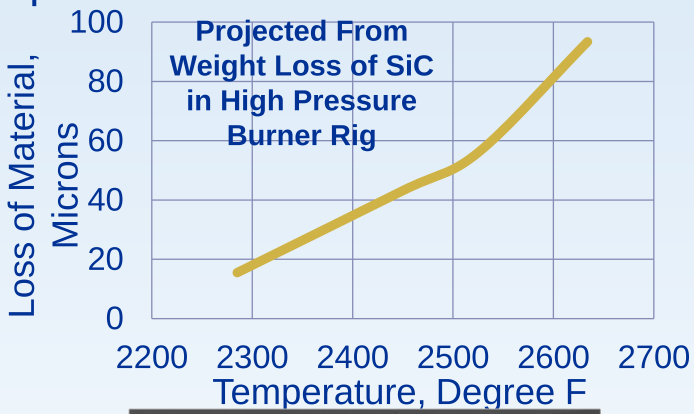
SiC fiber reinforced SiC ceramic matrix composite (SiC/SiC CMC) with 2700º F and higher capability

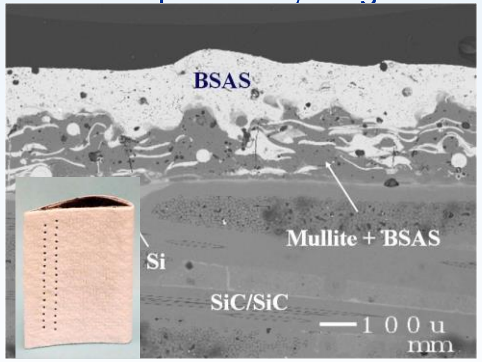




Key challenges:
- Higher temperature SiC fiber
- Low cost composite fabrication process
- Process modeling

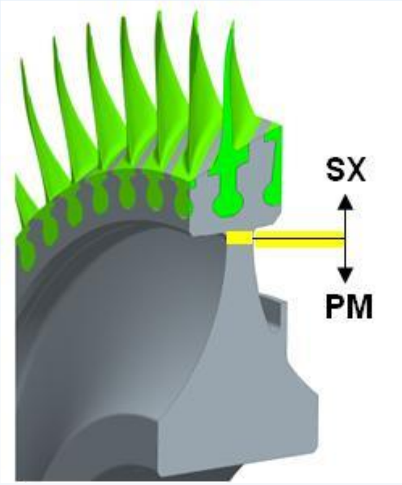
Environmental barrier coating (EBC) for SiC/SiC CMC





Key challenge:
- Durable and thin EBC at 2700ºF and higher temperature

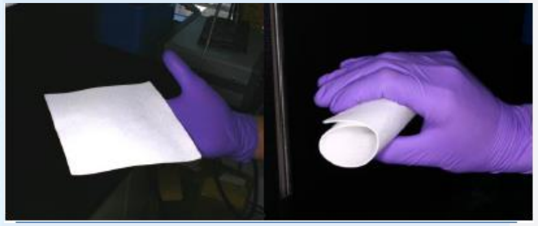
High temperature nickel-base disk alloy system with 1500ºF temperature capability



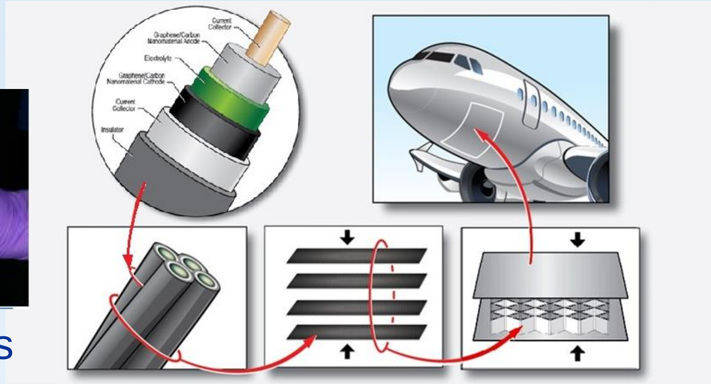
Key challenges:
- Desired properties in the bond between powder metallurgy alloy and single crystal alloy
- Thin hot corrosion resistant coating

Lightweight Materials and Structures

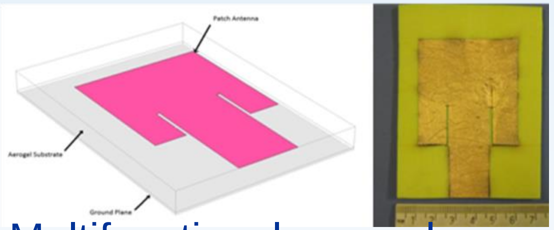
Strong, thin film polyimide aerogels



High temperature aerogels



Multifunctional structure with energy storage capability

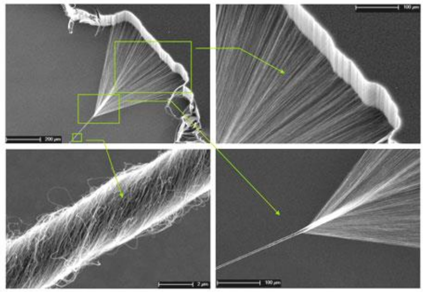


Multifunctional aerogel antenna

Normal PMC

Nanotoughened PMC

Toughening of PMCs through nanocmposite approach



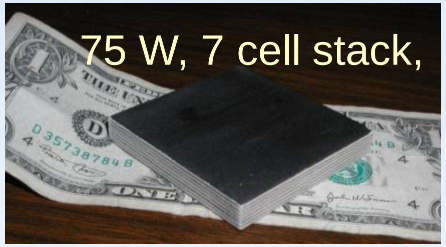
High strength carbon nanotube (CNT) yarn

Key challenges:

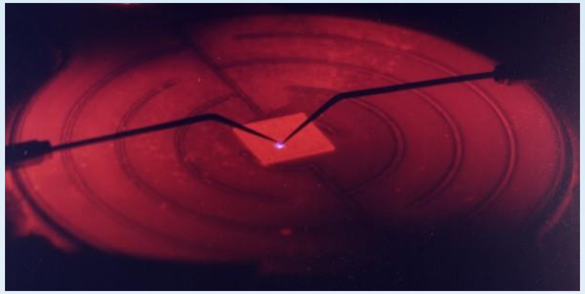
- Achieving greater than carbon fiber strength in CNT yarns, fibers, and sheets
- Design of viable multifunctional materials/structures
- Cost effective fabrication process for multifunctional/multimaterial structures with capability to engineer material at nanoscale

Electrical and Power System Materials

High Power Density Solid Oxide Fuel Cell (3X SOA)



Materials for high power density electric motor

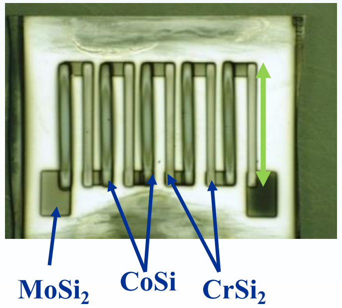


Materials for high power density power electronics

Small diameter superconducting MgB_2 fiber

Lightweight power transmission System

Thermoelectric-based energy harvesting



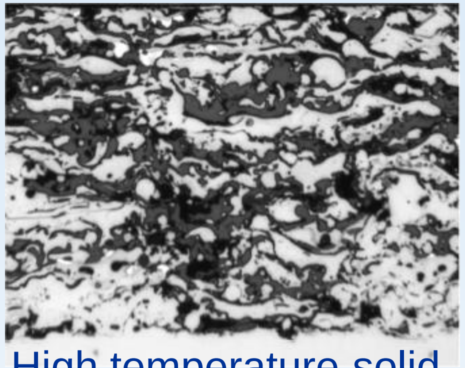
Key challenges:

- Materials with significantly higher electrical conductivity than Cu
- Magnetic materials with high magnetic strength and higher temperature capability
- Capacitors with higher temperature capability
- Electrically insulating materials with high thermal conductivity
- Defect free silicon carbide semiconductor

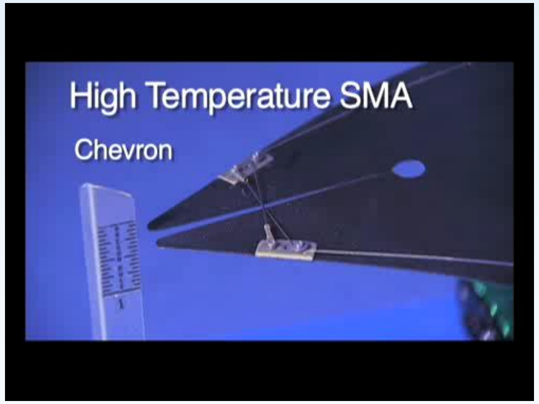
Lightweight and Durable Mechanical Systems/Mechanisms

Hybrid metal-PMC gear

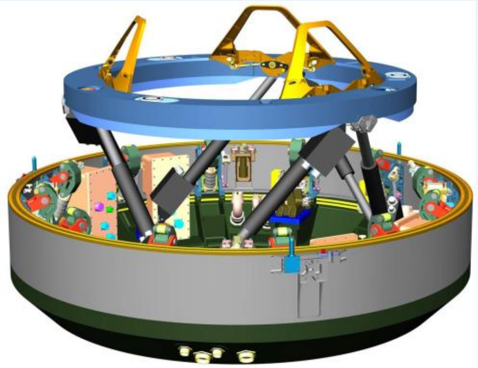
Superelastic bearing



High temperature solid lubrication coating



Lightweight actuation based on shape memory alloy



Seals for space environment

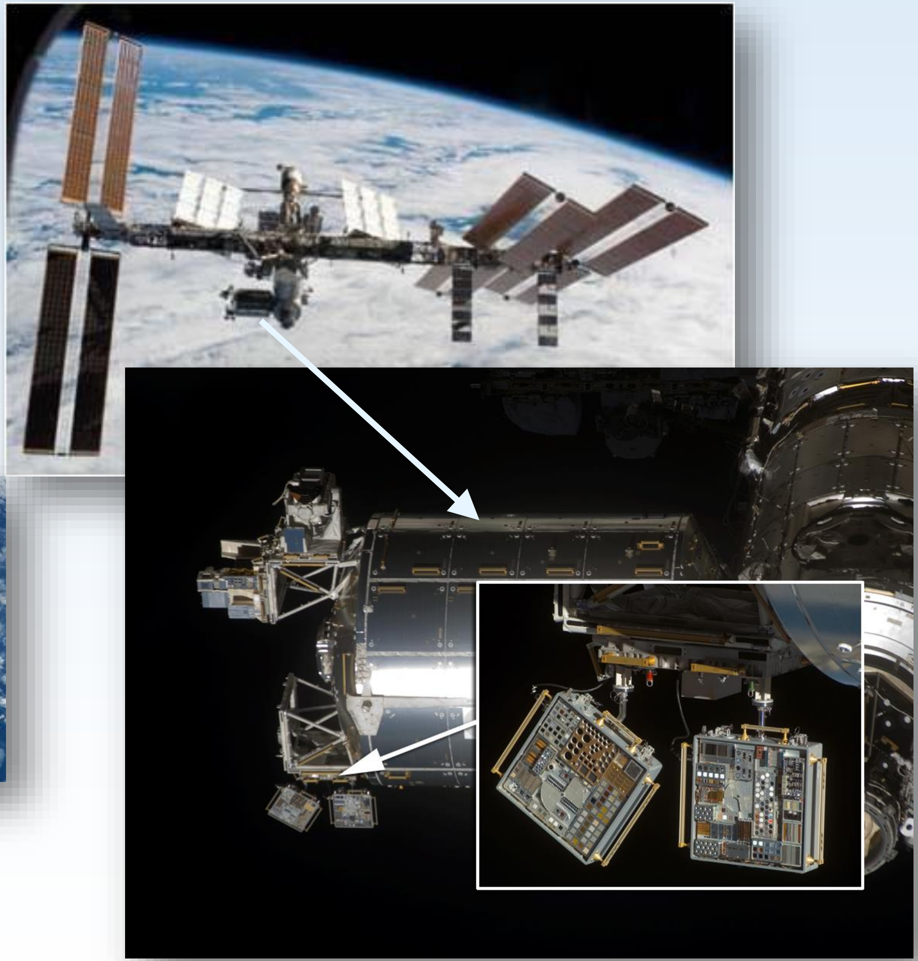
Rover tires based on superelastic materials

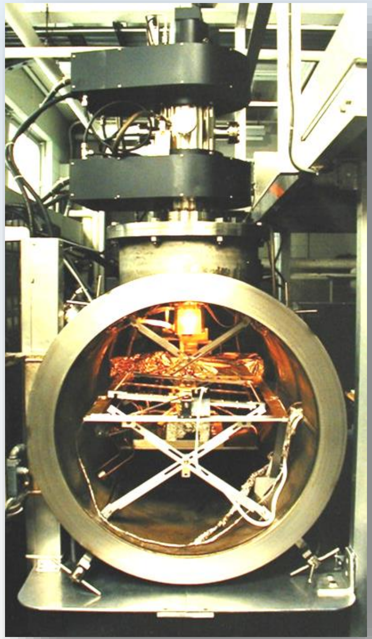
Key challenges:
- Cost effective manufacturing process for shape memory alloys (SMAs)
- Long-term durability of SMA-based actuation devices
- Liquid lubricants with high temperature capability
- Stability of lubricants in space environment (vacuum, dust)

Material Tests in Low Earth Orbit (LEO) for Environment Interactions

Atomic Oxygen Erosion on ISS

Materials International Space Station Experiment (MISSE)



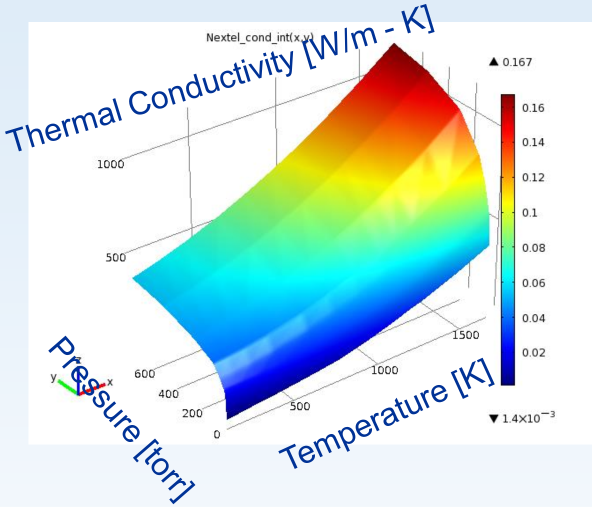


Atomic Oxygen Testing

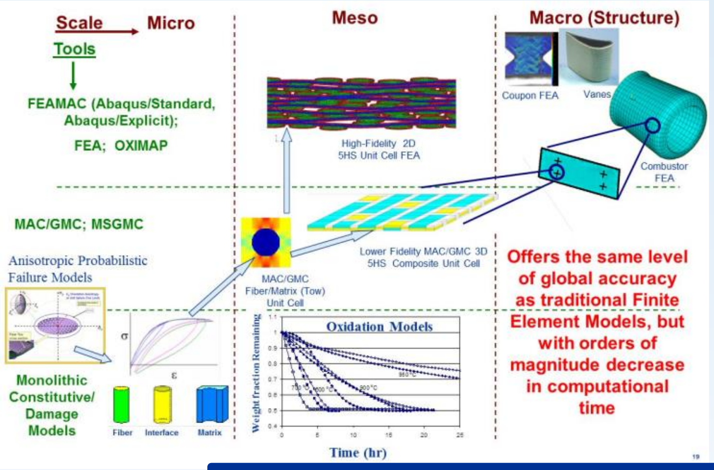
Long Duration Exposure Facility (LDEF)

Computational Modeling

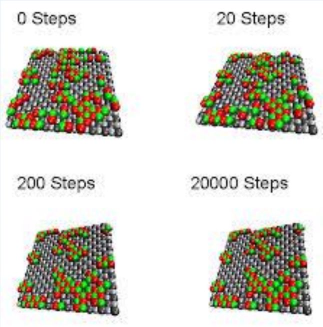
Modeling of Decomposition of Thermal Insulation



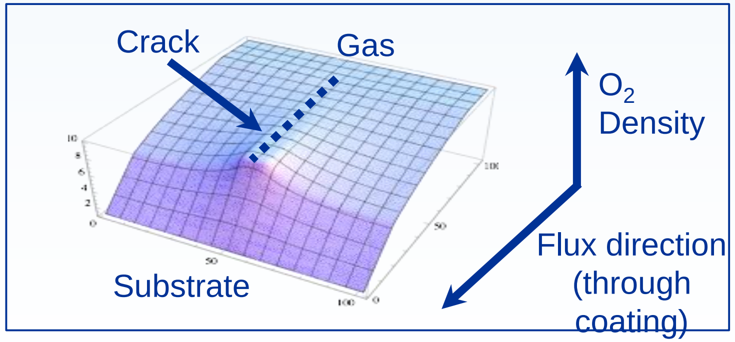
Multiscale Modeling of Composites



Kinetic Monte Carlo Simulation of Diffusion in Oxides



Environmental Degradation Modeling of Composites

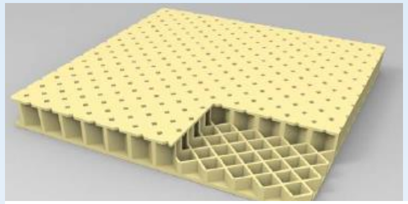


Key challenges:

- Process modeling for advanced materials fabrication and integration with multiscale model
- Modeling tools for design and development of multifunctional and multimaterial structures
- Use of material informatics and big data analytics to design and discover new materials

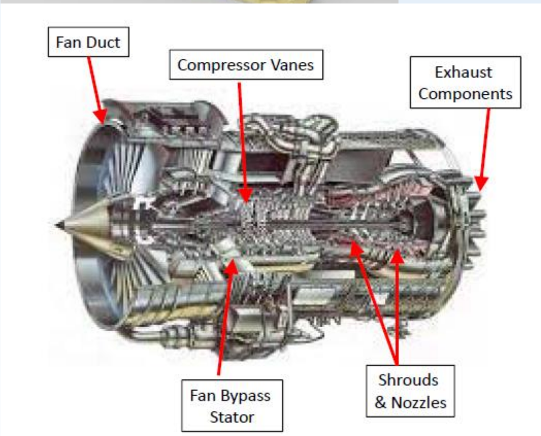
Additive Manufacturing R&D

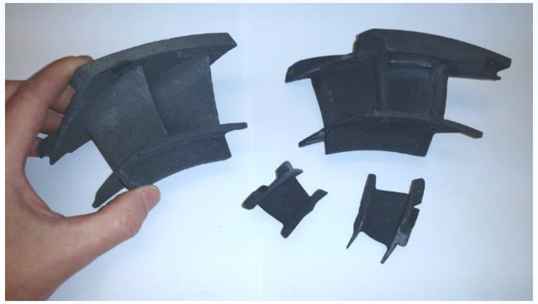
Non-metallic Gas Turbine Engine



Acoustic liner

Guide vane

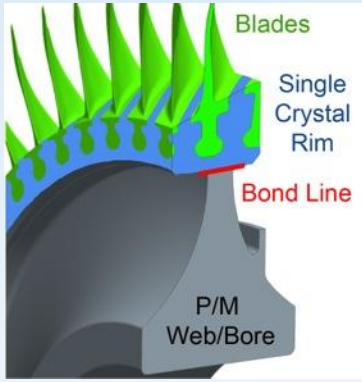


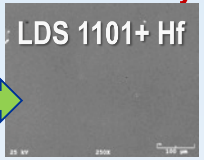


Additive manufacturing of CMC Vane

Additive Manufacturing of Hybrid Disk

Single Crystal Cast Rim Alloy



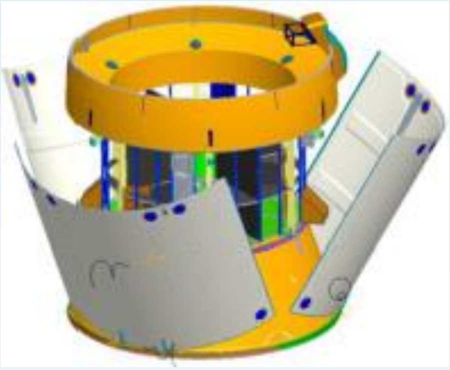


Bore/ Web Alloy

Regeneratively Cooled GRCop-84 Chamber

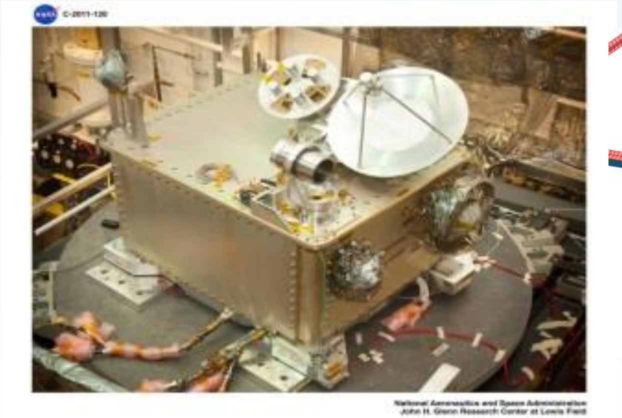
Development of Flight Structures

Orion Fairing Jettison

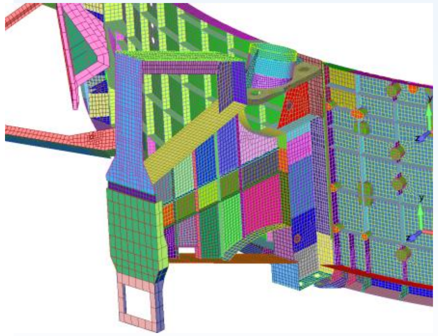


Large Scale Structure Testing

Orion Exploration Flight Test - 1



Flight Hardware Vibration Testing



Structural Analysis and Optimization

Large Composite Structures